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Production of Laminated Natural Fibre Board from Banana Tree Wastes

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Abstract

Laminated boards were produced by laminating banana stem fibre boards with banana leaf tapes. Various laminated boards were created by changing the number of layers of leaf tapes used. The tensile strength, elongation at break, flexural modulus and impact strength of the laminated boards increased with increasing number of layers of the leaf tapes. The elastic modulus of the laminated boards, however, showed the opposite trend. The orientation of fibre in the leaf tapes has little effect on impact strength but other properties studied showed that the properties measured along the fibre orientation were higher than that in the perpendicular direction.

Peer-review under responsibility of School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia

Keywords: banana wastes, fibre board, lamination

1. Introduction

Banana is the second most consumed fruit in Malaysia. It is estimated that about 10 million banana trees are cut down every year to produce enough banana to meet the demand in Malaysia. These banana trees are left to rot in the banana plantation and by product of the rotting process is methane gas which is one of the green house gases (a pollutant). It is worth to utilize fibre from banana trees since it is considered as one of the renewable resources in Malaysia and in the future the demand for banana stem fibre based will increase as green materials. Utilization of the banana stem fibre not only benefit the environment, but it will also reduce the overall resource consumption while sustaining national economic growth and introduction of green technology to the rural areas.

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Over the years, a lot of work had been done on the utilization of banana stem fibre[1-15]. Most of the work concentrated on making biocomposites based on banana stem fibre. Banana stem fibre based biocomposites were made by mixing banana stem fibre with other materials as the matrix. Different strategies were employed to produce biocomposites for different possible applications. Most work claimed that the resulting biocomposites were biodegradable.

The method of making banana stem fibre based biocomposites involved extracting the fibre from the banana stem. The fibre was then cleaned and processed based on the type of biocomposites to be produced. Sometimes the fibre surface was modified to ensure better interaction between the fibre and the matrix. One of the problems encountered in making biocomposites is homogeneity. Homogeneity is important to ensure that the fibre is uniformly dispersed in the composites. If the fibre is not uniformly dispersed in the biocomposites, the properties of the fibre-rich areas will be different from other areas in the biocomposites[9,14].

One of the methods of making biocomposites is by lamination. Lamination will ensure that the distribution and the orientation of the fibre can be controlled precisely in the biocomposites. Fibre orientation plays important role in biocomposites because the properties measured along the fibre orientation are usually higher that the properties measured in the perpendicular direction[3]. Biocomposites of uniform properties can easily be produced by crossing the fibre orientation in the different layers of the laminates.

In this study, banana stem fibre laminated boards were produced by laminating the banana stem fibre boards with banana leaf tapes. Various laminated boards were created by changing the number of layers of leaf tapes used and also the fibre orientation of the leaf tapes. The tensile and flexural properties of the laminated boards were mesasured to study the the effect of the number of layers and the fibre orientation of the leaf tape on the propertries.

2. Experiment

2.1. Production of banana sheets

Banana leaf was obtained from the banana garden at the Universiti Sains Malaysia were cut into the A4 size sheets. The sheets were cleaned by brushing them in the running tap water. The cleaned sheets were then soaked in a solution of glycerin and water (1 part of glycerin in 3 parts of distilled water) at 80^{o}C for 24 hours. After soaking, the sheets were wiped with a tissue paper and allowed to air dry at room temperature for 24 hours. After that the sheets were pressed using the hot press at 70^{o}C with a pressure of 100 kg/cm^2 until they were flat and completely dried.

1.2. Production of banana leaf tapes

Acrylic based double sided tapes were attached to one side of the sheets. A slight pressure was applied, by hand, to ensure that the double sided tape was attached properly to the banana leaf sheets. A rubber roller was used to squeeze any air trapped between the double sided tape and the banana leaf sheets. After that the assembly was pressed using the cold press at a pressure of 100 kg/cm^2 for 5 seconds.

1.3. Production of banana stem board

The banana stems, taken from the same source as mentioned in 2.1, were cut into small pieces using a machete. After washing in the running tap water, the banana stem pieces were dried at 100^{o}C in a convection oven for 24 hours. After that the dried banana stem pieces were ground using a high-speed grinder fitted with a screen of mesh number of 150µm. About 100.0 g of the ground banana stem was mixed with 35.0 mL of water, at room temperature. The resulting mixture was then transferred into a rectangular mould of dimensions of 21.0 cm x 21.0 cm x 0.5 cm. The mould was pressed with a pressure of 100 kg/cm^2 at 180^{o}C for 5 minutes and then the pressure was released. This process, called bumping, was repeated three times to allow water vapour to escape. After that mould was pressed at the same pressure and temperature for 20 minutes. The resulting board was allowed to cool down to room temperature under the same pressure for 30 minutes.

2.4 Production of laminated board

The laminated boards produced are made up of banana stem board as the core material and the banana leaf tapes as the skin. To make the laminated boards, the backing of the double-sided tape adhesive was first removed from the banana leaf tape. Then the adhesive side of the banana leaf tape was applied onto the banana stem board using the rubber roller to squeeze trapped air, and cold pressed with pressure of 100 kg/cm2 for 5 minutes. Two types of laminated boards were produced. The first type are boards with the banana leaf tapes fibre in different layers aligned in the same direction (parallel orientation) and the second type with banana leaf tapes fibre in different layers aligned in the cross direction (crisscross orientation).

2.5 Measurement of mechanical properties of laminated boards

Test specimens were cut from the laminated boards for tensile and three-point bending tests using a band saw (Hitachi Cb75f). All these tests were conducted at room temperature, and the average value of five repeated tests was recorded for each composition. The tensile test was performed using the INSTRON 5582 universal testing machine. The crosshead speed was set at 5 mm/min. The average thickness of the specimen was measured to be about 0.5 mm. Other parameters of the tensile machine and conditioning of the tensile specimens followed ASTM D882. Specimens with the size of 160 mm x 2 mm were used in the three-point bending test, performed using a Universal Testing Machine (Instron 5582) according to ASTM D1037 at a crosshead speed of 5mm/min. Charpy impact was done using the charpy digital impact testing machine according to ASTM D6110 standard. A 5ftlb pendulum was used to impact the test specimens (dimensions of 70 mm x 15 mm) that were cut from the laminated boards using the band saw (Hitachi Cb75f). The impact test was conducted at room temperature and the average value of five specimens was evaluated as the impact strength for each laminated board.

3. Results and discussion

3.1 Tensile properties

The effect of the number of layers and fibre orientation of the banana leaf tapes on the tensile strength of the laminated board is shown in Fig. 1. The tensile strength increased with the number of layers of the banana leaf tapes. This shows that banana leaf tapes can be used to reinforce the board. It could be seen that by laminating with 1 layer of banana leaf tape, the strength of the board along the banana leaf tape fibre orientation increased by 200% (from 0.5 to 1.5 MPa). However, as more banana leaf tapes layers are added, the increase in the tensile strength or reinforcement seemed becoming less. It is observed from Fig. 1 that the increase of the tensile strength when 4 layers of banana leaf tape are used is around 400%. The possible reasons for the reduction of the reinforcement are the increase in the amount of the acrylic adhesive used to laminate the board and also possible entrapment of air in between then banana leaf tapes layers. The acrylic adhesive is a soft viscous material. As more banana leaf tapes are layered to the banana stem fibre board, more viscous acrylic adhesive will be added to the laminated board. The increase in the viscous component will reduce the tensile strength of the board.

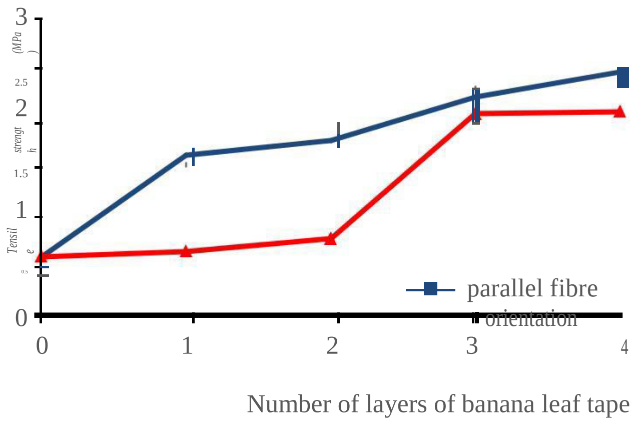

Fig. 1 Effect of the number of layers and fibre orientation of banana leaf tapes on the tensile strength of laminated banana stem fibre board.

It could be seen from Fig. 1 that the tensile strength of the laminated board with crisscross fibre orientation is lower than that of the parallel orientation. The reduction of the tensile strength is due to the fact that less fibre is oriented in the test direction. Therefore less fibre are able to support the force during tensile test as compared with the parallel orientation.

The elongation at break of the laminated board increases with increasing number of layers of banana leaf tapes, Fig. 2. Also as more layers of banana leaf tapes are used, the difference in the elongation at break between the parallel and crisscross fibre orientation is getting smaller. This shows that as more adhesive is added to the laminated board, the effect of fibre orientation is less significant. This is because when the laminated board is pulled, the adhesive layer will deform first because it is weaker than the banana leaf tape. Therefore the adhesive layer contributes to the elongation of the laminated board. This is evidence from the elongation of the laminated board containing 2 layers of banana leaf tape, which is greater than the board without lamination. As the number of layers of banana leaf tape is increased, the adhesive layer will also increase. Each adhesive layer will contribute to the elongation of the laminated board and thus the elongation of the board increases with increasing layers of banana leaf tape. This is because elongation at break of the laminated board depends on the viscous component contributed by the acrylic adhesive, not on the fibre in the banana leaf.

Comparing Fig. 1 and 2, it could be seen that by increasing the number of layers of banana leaf tapes the resulting laminated board is not only stronger but also tougher.

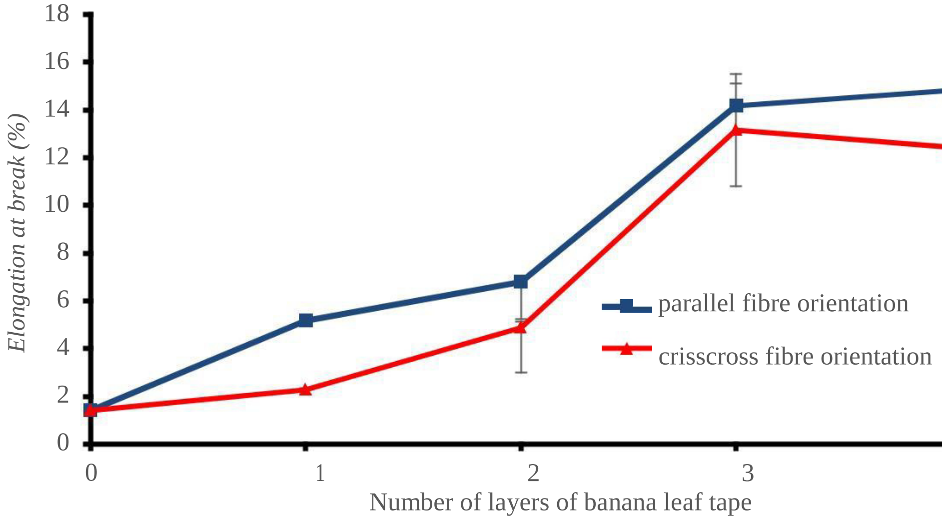

Fig. 2. The change of the elongation at break of the banana stem fibre laminated boards with the number of layers and fibre orientation of banana leaf tapes.

It seemed from Fig.3 that as more banana leaf tapes are added to the board, the resulting board is less rigid. The reduction of the elastic modulus is due to the increase in the viscous component in the laminated board. Since elastic modulus depends on the viscous component in the board, the effect of fibre orientation is not significant.

The tensile strength results shown in Fig. 1 – 3 suggests that the tensile properties of the laminated board could be controlled by changing the number of layers of leaf tapes and also the amount of viscous adhesive used. This means that if any part of the laminated board is not strong enough to support any load it could be strengthened by simply adding more layers of tapes. Therefore, lamination technique gives better flexibility and control in making the board to meet various service conditions. Since the integrity of the banana leaf was not destroyed in making the laminated board, the problem of inhomogeneous fibre distribution will not occur as sometimes encountered in conventional composites.

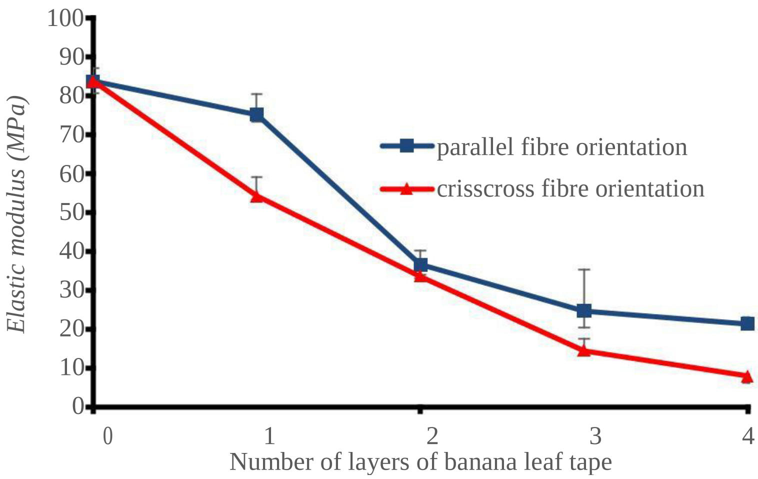

Fig.3. The reduction of the elastic modulus of the banana stem fibre laminated board with the number of layers and fibre orientation of the banana leaf tapes.

3.2 Flexural modulus

Fig. 4 shows the effect of layers and fibre orientation of the banana leaf tapes on the flexural modulus of the laminated boards. Increasing the number of layers of the banana leaf tapes increases the flexural modulus of the laminated board. The effect of fibre orientation on the flexural modulus is significant when the number of layers is greater than 2. The flexural modulus increased by 500% when the number of layers of banana leaf tape was increased to 4.

During bending test, it was observed that the bending test specimens did not fail completely, only the core material fractured but the skin material was intact. From this observation, it could be inferred that during bending, the skin absorbed most of the force applied. The excessive force has been transferred to the core material. The weak core material has fractured instantaneously. The whole specimen fail.

The flexural modulus of the laminated board is related to the tensile strength, as shown in Fig.5. It could be seen that the flexural modulus for parallel and crisscross fibre orientations fall on the same curve. This relationship is true since during bending, one side of the laminated board experienced stretching and the other side experience compression. The stretching side bore most of the bending force and when this side failed, the force will be transferred to the core. Therefore the skin material with higher tensile strength can absorb more force and thus the laminated board will have higher flexural modulus.

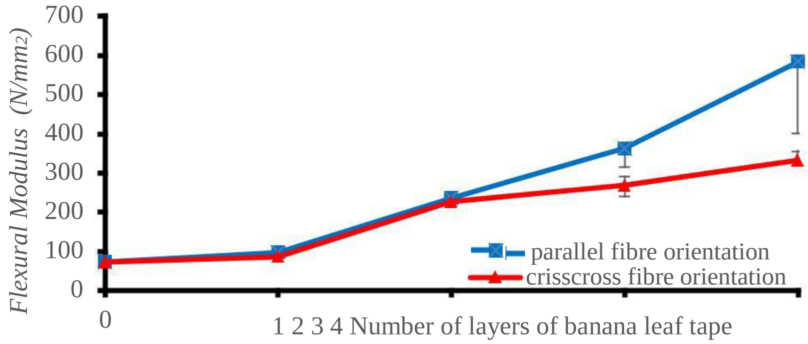

Fig. 4. Effect of the number of layers and fibre orientation of banana leaf tapes on the flexural modulus of banana stem fibre laminated boards.

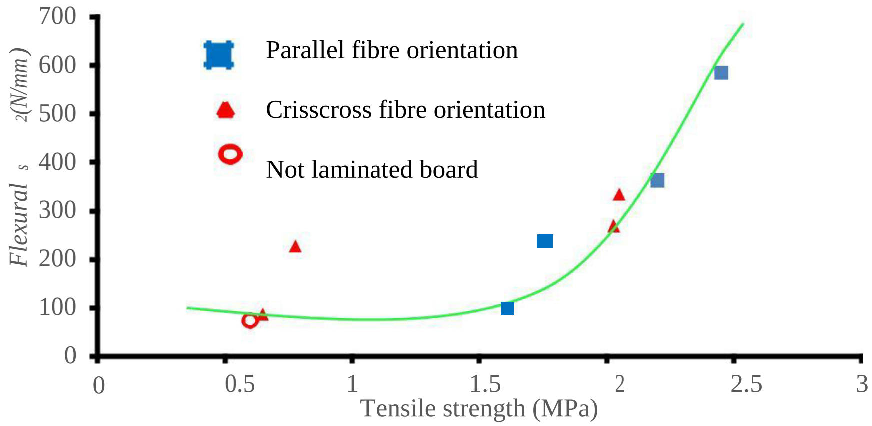

Fig.5. The dependence of the flexural modulus on the tensile strength of the laminated boards.

3.3 Impact strength

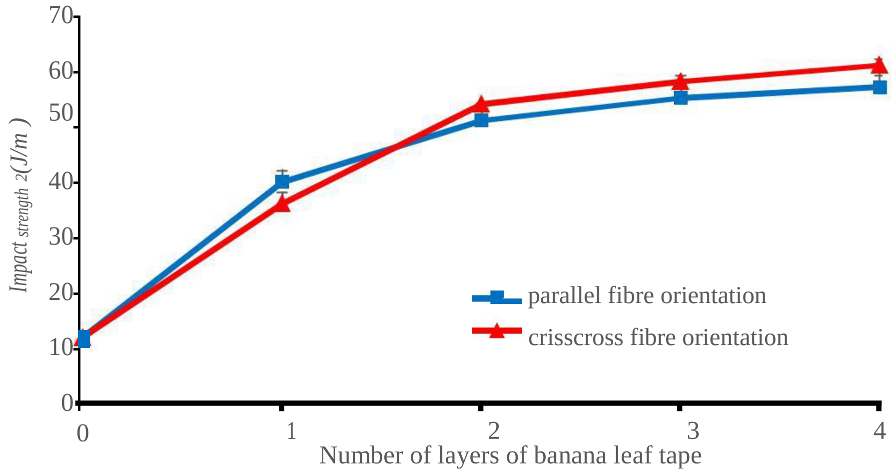

Fig. 6. Effect of the number of layers and fibre orientation of banana leaf tapes on the impact strength of banana stem fibre laminated boards.

The dependence of impact strength on the number of layers and fibre orientation of the banana leaf tapes is shown in Fig. 6. It could be seen that the impact strength is related to the number of layers of the banana leaf tape. The effect of fibre orientation on the impact strength is insignificant. The reason for this is that impact strength of the board is dependent on the toughness of the board. The toughness of the board is dependent on the viscous component provided by the adhesive. As the number of layers of the banana leaf tape is increased, more adhesive is used in the board and thus the viscous component increases. Therefore the impact strength of the board will increase.

Fig. 7 shows the effect of viscous component in the board on the impact strength. The amount of viscous component in the laminated boards is reflected in the values of the elastic modulus of the laminated board. Boards with more viscous component will have lower elastic modulus. From Fig.7, it could be seen that board with low elastic modulus (more viscous component) has higher impact strength.

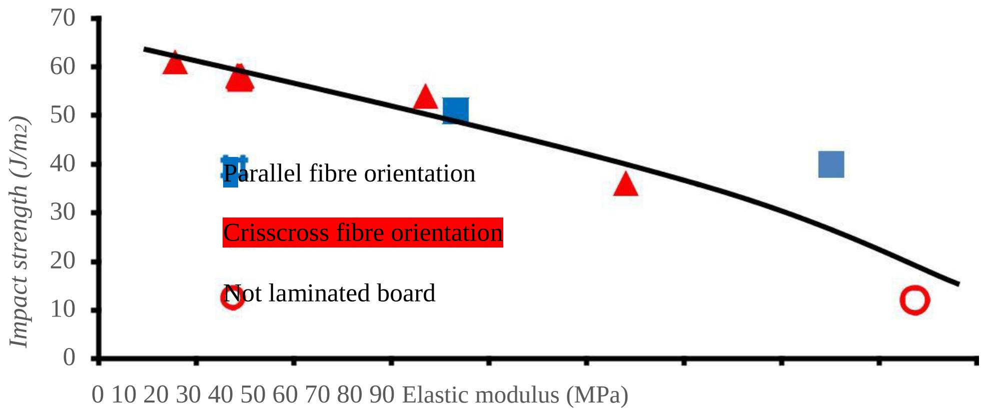

Fig. 7. The relationship between impact strength and the elastic modulus of the laminated boards.

4. Conclusion

Increasing the number of layers of the banana leaf tapes increases the tensile strength, elongation at break, flexural modulus and the impact strength of the laminated boards. The elastic modulus, however, showed the opposite trend. The fibre orientation of the banana leaf tapes has no significant effect of the properties measured. The flexural modulus of the laminated board is related to the tensile strength and thus is not dependent on the viscous component in the board.The impact strength, on the other hand, is dependent on the viscous component in the laminated boards.

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